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LUMINARY Memo #162

To: Distribution
From: D. Eyles
Date: 20 July 1970
Subject: A New Landing Analog Displays Routine

This memo describes a new Landing Analog Displays (LAD) routine now running and essentially complete in revision 31 of off-line program ZERLINA. A copy of PCR 1058 for its incorporation in LUMINARY is attached.

This version aims at reducing computational errors to zero. By computational errors I exclude Servicer's state vector errors, including only those errors due to imperfect extrapolation of Servicer data. Specifically, these weaknesses of the incumbent LAD had to be cured: (1) a periodic "lurch" in the altitude-rate displayed on the tape meter, caused by a time-inconsistency in the LAD-Servicer interface, (2) excessive granularity of the DSKY display — in R1 of noun 60 during P66 — of forward velocity, and (3) inaccuracy of the cross-pointer displays.

These problems were attacked (1) by insuring time-consistency of the LAD inputs from Servicer, (2) by adding a PIPA bias correction term to the velocity computation which is the starting point of the LAD calculations, (3) by a more adroit choice of scaling, and (4) by the use of double-precision arithmetic at strategic points, partially compensated for, in terms of execution time, by simplifications elsewhere. Also, care was taken to avoid the possibility of cumulative errors, the bane of an open loop driven incrementally.

Tests show that the design objective — in a word, accuracy — is achieved. Bob Covelli, who wrote an edit for the purpose, observed computational errors in the old version of up to 6 bits. (One bit is worth .5571 f/s.) This error is reduced to at most one bit. More important, in the neighborhood of zero velocity the maximum error is less than a bit, because velocity is rounded to the <u>nearest</u> bit before being displayed. This means that when forward or lateral velocity exceeds about .3 f/s, either way, the cross-pointers can be relied upon to show it as non-zero. Thus in switching into P66 Auto from attitude-hold with the spacecraft erect and the cross-pointers at zero no

perceptible attitude transient will occur. In the old version velocity sometimes has to be more than 1.2 f/s for the cross-pointer to move away from the zero mark. The accuracy of the altitude-rate display is also improved, and the annoying "lurch" eliminated.

This new LAD routine saves about 90 words of fixed memory. Its erasable storage requirements are down to 32 cells from 40 cells. In execution time the new version takes about 1.5 ms. more than the old version every 1/4 second, plus 5 ms. more every 2 seconds, a dutycycle increase of about .85%.

The major changes involved are next described. Note that items C - E are positive improvements not directly inspired by the shortcomings of the old version.

A. The addition of a PIPA bias correction term to the velocity vector computation was thought worthwhile. The PIPA compensation scaling allows for a bias of up to 12.5 cm/s over 2 seconds, and a bias of this size would affect the accuracy of the LAD displays significantly. The velocity computation becomes:

$$\underline{V}VECT = \underline{V} - \underline{V}SURFACE + (\underline{P}IPA - \underline{P}IPAOLD) + (\underline{G}\text{-}VBIAS)\ DT.$$

$\underline{V}$ is the velocity vector for PIPTIME, $\underline{V}$SURFACE is the lunar surface velocity, both from Servicer. $\underline{P}$IPAOLD contains the contents of the PIPAs at PIPTIME; it also comes from Servicer, as described in Luminary Memo #152 about the Cyclical PIPA Reader. $\underline{G}$-VBIAS (only one mnemonic) is computed by Servicer every pass as the acceleration due to gravity minus the pseudo-acceleration due to PIPA bias. The computation of VBIAS (needed by P66ROD) formerly done at the start of P66 was moved to NORMLIZE (the Servicer job lead-in) and $\underline{V}$BIAS in turn is used every pass in the computation of $\underline{G}$-VBIAS. DT is simply time since PIPTIME. All the vectors are in stable-member coordinates.

B. In addition, a simpler altitude extrapolation is used than before, one analogous to the position computation in average-G where the average of velocities at either end of an interval is used to extrapolate position.

$$ALTITUDE = HCALCLAD + \frac{ALTRATE + HDOTLAD}{2}\ DT$$

where HCALCLAD and HDOTLAD are altitude and altitude-rate at PIPTIME provided by Servicer. ALTRATE is the current altitude-rate calculated just before in the LAD routine.

C. An additional advantage of the new LAD is that it starts displaying when average-G is turned on at TIG -30 seconds instead of waiting for ignition. LAD never <u>had</u> to wait for ignition and by enabling itself earlier provides an additional confirmation that Servicer is working properly before the engine is lit. The flag SWANDISP which enables the displays is set by Servicer whenever it provides the interface variables; this first occurs soon after TIG - 30 seconds. Formerly SWANDISP was set at TIG by descent and ascent programs.

D. The new LAD effectively issues tape meter updates with twice the frequency of the old routine, every 1/4 second instead of every 1/2 second. This is because the old routine issues altitude and altitude-rate alternately, each every 1/2 seconds. But since it is the channel bits which are set following the altitude output that actually cause the meters to move, altitude-rate has to wait 1/4 second before being seen. This is objectionable, since in computing altitude-rate we take such pains to be up-to-date. In the new version altitude-rate is output before a 3 centisecond break (necessary anyway to fragment this long interrupt) and altitude afterwards. Without a break this would be impossible as time must be allowed for altitude-rate to be read out of the ALTM register (ECADR 60) before altitude is put in. Since the altitude computation is a quick one, and altitude cannot be computed without first getting altitude-rate, very little computation time would be saved by forcing the new LAD to emit these displays with the old frequency. And it would cost words.

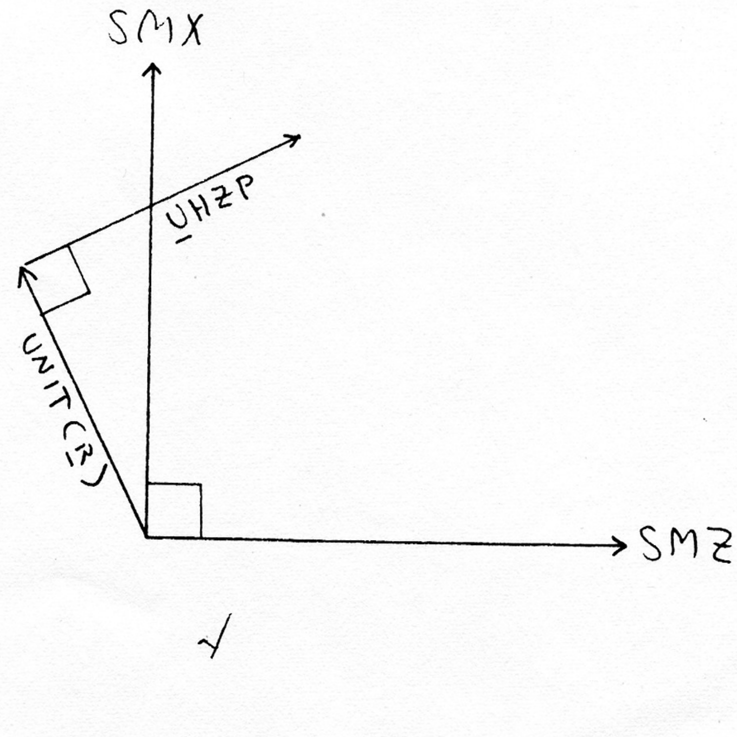
E. Finally, the R10FLAG, which used to prevent the computation and display on the cross-pointers of forward and lateral velocity during ascent and aborts, is eliminated. Lateral velocity, in particular, may be useful in telling whether an ascent burn has an out-of-plane component. Involved in the cross-pointer calculations is the assumption that the stable-member y-axis is approximately normal to the LM (and CSM) orbital plane. This is the normal alignment for ascent, but since the assumption is not made anywhere else in the ascent coding, it should be explicitly recognized that the accuracy of the

cross-pointer displays during ascent depends on its validity.

Now a word on computational simplifications.

The Landing Analog Displays begin by computing a velocity vector, relative to the surface. This vector is projected along (dotted with) unit vectors RUNIT, UHYP and UHZP to get altitude-rate, VHY and VHZ, and finally VHY and VHZ are resolved into forward and lateral velocity according to the outer gimbal angle. Great simplifications are possible in the area of the dot products, saving execution time (expended elsewhere) and making possible the elimination of the erasables UHYP and UHZP, for a total of 12 cells in ebank 7, four of which are expended.

The key assumption is the identity of UHYP and the stable-member y-axis. This assumption is easily made — at least for descent — since they are defined the same way, as the northward or right-hand normal to the LM (and CSM) orbital plane. That the two are equivalent is assumed already in the final stage of the cross-pointer computations, where the sine and cosine of the outer gimbal angle are used to resolve VHY and VHZ into forward and lateral velocity, so the two might as well be identified, and the vector UHYP eliminated entirely. VVECTY becomes VHY. Furthermore, since UHZP = UNIT(R) * UHYP, the y-component of UHZP disappears, and with it the middle term of the VHZ dot product. Finally, note from this drawing



in which the stable-member y-axis extends out of the page toward you, that

UHZPX = - RUNITZ

UHZPZ = RUNITX.

This permits the elimination of $\underline{\text{UHZP}}$.

It has been suggested that the y-component of the altitude-rate dot product can also be eliminated. This is true for the so-called landing alignment but not necessarily true for ascent. Although the assumption of this alignment is made for the cross-pointer computations (as noted above in E) it was not thought best to make it for the more essential computation of altitude-rate.

Next come descriptions of LAD inputs and outputs, a flowchart, and a copy of PCR 1058.

INPUTS

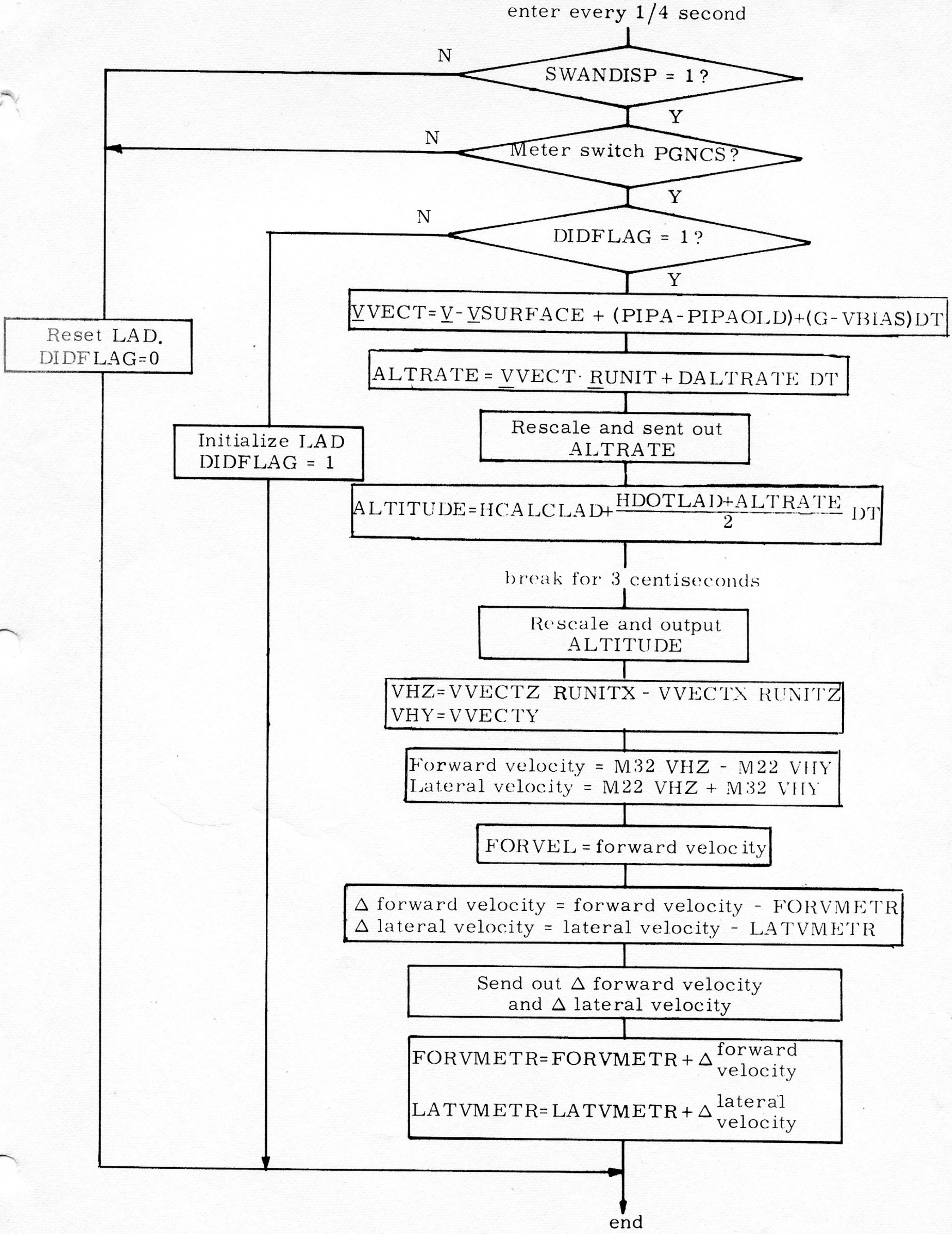
Besides the current contents of the PIPAs LAD's inputs are these, provided by Servicer unless otherwise noted:

V	Velocity at PIPTIME, SM coordinates, scaled in units of 2^7 m/cs. Three DP components
VSURFACE	Lunar surface velocity, SM coordinates, scaled in units of 2^5 m/cs. Three DP components. This replaces DELVS but has the opposite sign.
G-VBIASX, Y, Z	Acceleration due to gravity minus pseudo-acceleration due to PIPA bias, SM coordinates, in units of 2^{-9} m/cs/cs. Three SP components.
RUNITX, Y, Z	Unit position vector, SM coordinates, scaled full-size. Three SP components.
PIPAOLD	(Actual mnemonics PIPAXOLD, PIPAYOLD, and PIPAZOLD) The contents of the PIPAs as of PIPTIME (see Lum. Memo #152). Three SP components.
PIPTIME	Time at which all these numbers are valid, TIME2 units. DP scalar. (Actually, only the low-order part is used.)
HCALCLAD	Altitude at PIPTIME, in units of 2^{15} meters, a DP scalar.
HDOTLAD	Altitude-rate at PIPTIME, in units of 2^5 m/cs, a DP scalar.
DALTRATE	Rate-of-change of altitude-rate due to change in the direction of RUNIT, scaled in units of 2^{-9} m/cs/cs, a SP scalar.
M22	Sine of the outer-gimbal angle, full-size, kept up to date by the DAP, a SP scalar.
M32	Cosine of the outer-gimbal angle, full-size, kept up to date by the DAP, a SP scalar.

OUTPUTS

Besides its outputs to the cross-pointers and tape meters, LAD maintains the following variables, never more than 1/4 second old while LAD is running:

$\underline{V}$VECTX, Y, Z	Velocity relative to the lunar surface in SM coordinates, in units of 2^5 m/cs. Three DP components.
ALTITUDE	Altitude in units of 2^{15} meters.
ALTRATE	Altitude-rate in units of 2^5 m/cs. (This could be used for R2 of nouns 60, 63, 64, and 92 for the DSKY altitude-rate display to be more up-to-date when it appears.)
FORVMETR	Forward velocity in meter units, .5571 f/s/bit, a SP scalar.
LATVMETR	Lateral velocity in meter units, .5571 f/s/bit, a SP scalar.
FORVEL	Forward velocity for DSKY display, units of 2^5 m/cs, a DP scalar.


enter every 1/4 second
SWANDISP = 1 ?
N
Y
Meter switch PGNCS ?
N
Y
DIDFLAG = 1 ?
N
Y
VVECT=V-VSURFACE + (PIPA-PIPAOLD)+(G-VBIAS)DT
ALTRATE = VVECT · RUNIT + DALTRATE DT
Rescale and sent out ALTRATE
ALTITUDE=HCALCLAD+ (HDOTLAD+ALTRATE)/2 DT
break for 3 centiseconds
Rescale and output ALTITUDE
VHZ=VVECTZ RUNITX - VVECTX RUNITZ
VHY=VVECTY
Forward velocity = M32 VHZ - M22 VHY
Lateral velocity = M22 VHZ + M32 VHY
FORVEL = forward velocity
Δ forward velocity = forward velocity - FORVMETR
Δ lateral velocity = lateral velocity - LATVMETR
Send out Δ forward velocity and Δ lateral velocity
FORVMETR=FORVMETR + Δ forward velocity
LATVMETR=LATVMETR + Δ lateral velocity
Reset LAD. DIDFLAG=0
Initialize LAD DIDFLAG = 1
end

APOLLO SPACECRAFT SOFTWARE CONFIGURATION CONTROL BOARD PROGRAM CHANGE REQUEST

NUMBER (Completed by FSB): 1058

1.0 COMPLETED BY ORIGINATOR

1.1 ORIGINATOR	DATE	1.2 ORGANIZATION	APPROVAL	DATE
EYLES	July 6, '70	MIT		

1.3 EFFECTIVITY	1.4 TITLE OF CHANGE
LUMINARY 1E (Apollo 15)	New Landing Analog Displays (R10)

1.5 REASON(S) FOR CHANGE
See attached sheet.

1.6 DESCRIPTION OF CHANGE
See attached sheet.

2.0 SOFTWARE CONTROL BOARD OR FLIGHT SOFTWARE BRANCH DECISION FOR VISIBILITY IMPACT ESTIMATE BY MIT

2.1 ☐ APPROVED ☐ DISAPPROVED

2.2 REMARKS:

2.3 SOFTWARE CONTROL BOARD OR FLIGHT SOFTWARE BRANCH SIGN OFF

DATE

3.0 MIT VISIBILITY IMPACT EVALUATION:

3.1 SCHEDULE IMPACT

3.2 IMPACT OF PROVIDING DETAILED EVALUATION

3.3 STORAGE IMPACT

3.4 REMARKS:

3.5 MIT COORDINATOR

DATE

4.0 SOFTWARE CONTROL BOARD ACTION

4.1 ☐ IMPLEMENT AND PROVIDE DETAILED CHANGE EVAL. ☐ PROVIDE DETAILED CHANGE EVALUATION ☐ DIS-APPROVED

4.2 REMARKS

4.3 SOFTWARE CONTROL BOARD SIGN OFF

DATE

5.0 MIT DETAILED PROGRAM CHANGE EVALUATION

5.1 MIT COORDINATOR

5.2 MIT EVALUATION

DATE

6.0 SOFTWARE CONTROL BOARD DECISION ON MIT DETAILED PROGRAM CHANGE EVALUATION

6.1 ☐ START OR CONTINUE IMPLEMENTATION ☐ DISAPPROVED OR STOP IMPLEMENTATION

6.2 REMARKS:

6.3 SOFTWARE CONTROL BOARD SIGN OFF

DATE

APOLLO SPACECRAFT SOFTWARE CONFIGURATION CONTROL BOARD

-DATA AMPLIFICATION SHEET -

PAGE____OF____

PROGRAM CHANGE REQUEST NO. 1058	PREPARED BY: EYLES DATE: July 6, 1970	ORGANIZATION: MIT

CONTINUATION SECTION (REFER TO BLOCK NUMBER AND TITLE ON PROGRAM CHANGE REQUEST FORM)

1.5 Reasons for Change:

(1) Eliminate errors in forward and lateral velocity displayed on the cross-pointers.

(2) Eliminate the periodic "lurch" in the altitude-rate displayed on the tape meter.

(3) Correct error and excessive granularity of the forward velocity displayed in R1 of noun 60 (during P66).

(4) Speed up display of altitude and altitude-rate (display each every 1/4 second instead of every 1/2 second as at present).

(5) Begin displaying analog data at TIG - 30 seconds when average-G is turned on instead of waiting for ignition.

(6) Eliminate the R10FLAG so that cross-pointer displays be available during ascent and aborts as well as descent.

1.6 Description of Change:

Incorporate in LUMINARY the LAD routine now running in off-line program ZERLINA. GSOP impact aspects of this change are (1) the addition of a PIPA bias correction term to the velocity computation which is the starting point of the LAD computations, and (2) a simpler altitude extrapolation:

$$\text{ALTITUDE} = \frac{\text{HDOTLAD} + \text{ALTRATE}}{2}\,\text{DT} + \text{HCALCLAD}$$

where HDOTLAD and HCALCLAD are altitude-rate and altitude at PIPTIME, DT is time since PIPTIME, and ALTRATE is the current altitude-rate computed by LAD. Items 4-6 under "Reasons for Change" may require minor GSOP modifications, too.

REMARKS

This change is not dependent on approval of the Variable Guidance Period Servicer (PCR 1024) but could most conveniently be put into LUMINARY at the same time as that larger change.

TP#21812